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Chapter 16

Macronutrients N P K, levels and management

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ABSTRACT

The macronutrients nitrogen (N), phosphorous (P) and potassium (K) play a major role in coral growth and in the management of an artificial coral reef aquarium. Nitrogen, mostly measured as nitrates, was the first element aquarists cared about. Since the end of the nineties phosphorous gained more and more attention and it proved to play a very important role in water chemistry. Phosphorous is not only a macronutrient but also recognized as an inhibitor of hard coral growth. The latest element coming up is potassium. In 1992 potassium was identified to play a role in coral growth. But there was no adequate and cheap measurement available - so it was trial and error and experience. Since 2006 at least two aquaria tests have been available, but up to now they both deliver very rough values with some uncertainty.

The cycles of nitrogen and phosphorous as well as natural and aquarium levels are discussed and opportunities to manage these levels in closed systems will be shown. Normally nitrates and phosphates are looked at as long term parameters. But when managed near the growth limiting level (especially phosphates) nitrates and phosphates become short term parameters which have to be balanced very carefully. The present knowledge about potassium will be discussed and recommendations given for further investigations.

INTRODUCTION

There is no life without nitrogen (N), phosphorous (P) and potassium (K) and therefore these elements are major ingredients of fertilizers in agriculture. But coral reefs exist in warm, nutrient poor water, in the „deserts of the sea". Of N, P and K only K is rich, but N and P are very short. Nevertheless coral reefs belong to the biotopes on earth with the highest primary production similar to tropic rain forests. This is possible due to accumulation and recycling of nutrients inside the foodwebs of coral reefs and also due to the high mass transfer which is generated by the currents. Even on these very low levels of nutrients corals never lack nutrients because there is a huge reservoir of these low level nutrients around the reefs.

In most aquaria without a high exchange with fresh, natural seawater the situation is very different. The water volume is small relative to the amount of corals. This could lead to rapid depletion of nutrients. On the other side in most coral reef aquaria fish and some invertebrates are kept and fed so there is a constant input of nutrients which might exceed the uptake by the corals and lead to nutrient levels far above natural levels. In this paper natural levels are given as well as recommendations for nutrient levels in aquaria. The pathways of nitrogen and phosphorous inside aquaria will be shown and the possibilities outlined to influence these pathways and by this the nutrient levels to reach conditions for good and healthy growing corals.

Potassium K is different. Potassium is one of the most abundant elements in seawater. But as it is used up by primary producers the question remains open whether it runs into deficiency or not. There is some evidence that at least some aquaria may lack potassium and that coral growth is reduced.

Natural levels of N, P and K

The following table show natural levels of nitrogen, phosphorous (Sorokin, 1995) and

Table 1: Natural levels of nitrogen, phosphorous and potassium.

Levels of	inorganic N / P / K (µmol.L^{-1})	as NO_3 / PO_4 / K (mg.L^{-1})	organic N / P (µmol.L^{-1})
N in coral reefs	0.6 - 1.5 peak 11	0.037 - 0.093 peak 0.682	3 - 6 peak 22
N in surrounding water	0.2 - 0.8	0.012 - 0.05	1.0 - 4.0
P in coral reefs	0.02 - 1.4 peak 3	0.002 - 0.13 peak 0.28	0.1 - 0.2 peak 1.6
P in surrounding water	0.1 - 0.4	0.009 - 0.038	0.1 - 0.2
K	1,020	380	

potassium in coral reefs and the surrounding waters.

The lower levels of inorganic N and P in the surrounding waters, 0.012 mg.L^{-1} NO_3 and 0.009 mg.L^{-1} PO_4 clearly indicate the „desert" character of the surrounding waters.

N and P in aquaria

Early scientific coral aquarists like Jaubert (1991) and Adey and Loveland (1991) very much focused on nitrogen to manage water quality in coral reef tanks. The reduction or elimination of nitrates by denitrification (Jaubert) or algal turf scrubbers (Adey and Loveland) was the main purpose in each case. The discussion about cyanobacteria in low nutrient coral reef aquaria (Knop, 1994; Pawlowsky, 1996) showed that in some aquaria the absence of nitrates may cause the starvation of corals and higher algae while at the same time nitrogen fixing cyanobacteria overgrow larger parts of the tanks. During the nineties phosphorous gained more and more attention (Luther and Pawlowsky, 1997; 1998a; 1998b; 1999a; 1999b) and meanwhile seems to be more important for successful keeping and propagation of corals than nitrogen. Phosphate removing materials are well distributed among reef keeping aquarists.

Nitrogen

The nitrogen cycle inside the aquarium is shown in Figure 1.

Not all of the pathways mentioned in Figure 1 do exist in every aquarium, some need special equipment or requirements.

In the very most cases nitrogen is introduced

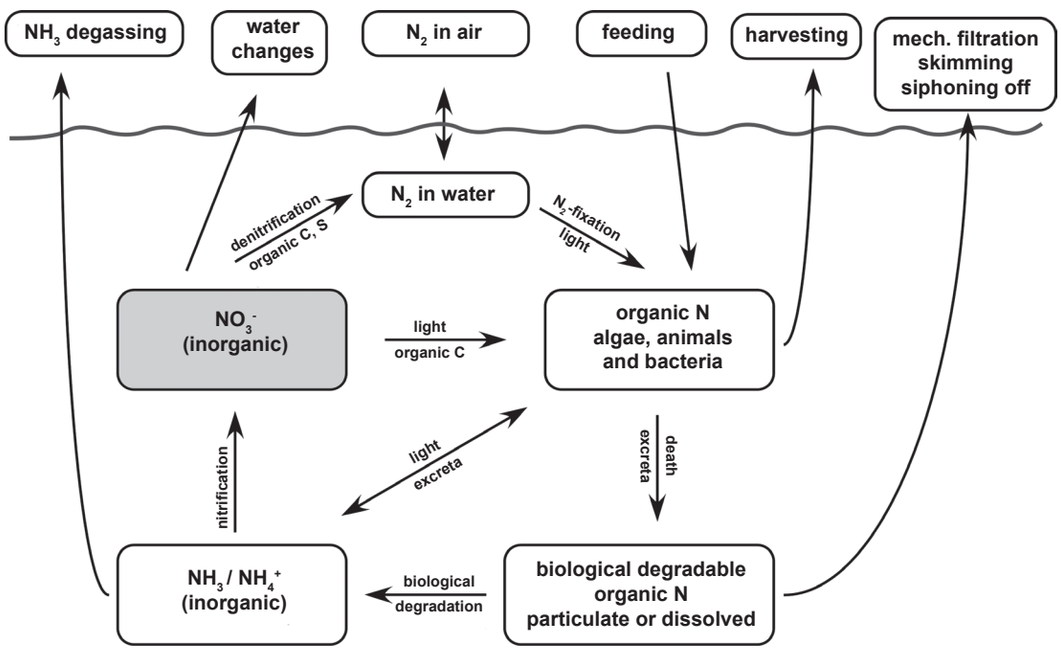

Figure 1: Nitrogen cycle in aquaria.

into the aquarium by feeding fish and invertebrates. Most of the nitrogen fed to fish is excreted as ammonia NH_4^+ by the fish and does not occur as organic N afterwards. After the start up of the aquarium nitrification is established and ammonia and organic N are converted to nitrates without measurable ammonia or nitrites. As an aquarium is not sterile bacteria immediatly start feeding on organics when these occur somewhere in the system. This process takes place even without special biofilters because whenever there is periodic feeding bacteria immediately start to grow and they develop stable populations. They live on every surface (decoration, bottom sand and walls) and even in larger numbers in the open water if the food supply is high. The result is that the bacteria inside the tank and the bacteria in a biofilter and a foam fractionater compete for organics which may either be degraded or skimmed.

Biofilters are nothing else than additional surfaces with a controlled water flow to pass ammonia and organics along the settled bacteria which convert the ammonia and organics to NO_3^-, H_2O, CO_2 and PO_4^{3-}. By this biofilters do not remove nitrogen from the system but remove ammonia and degradable organics from the water.

Avoiding a biofilter in the system does not avoid nitrification of the ammonia and therefore the increase of nitrates. Nitrification only takes place somewhere else in the system. A well designed biofilter does not work as a mechanical filter i. e. it does not collect particles and clog. But with passing time filter feeders will settle in the biofilter which then also turns to be a big filter feeder and a competitor for food of the corals in the tank.

Foam fractionaters, also called „protein skimmers“, are often believed to remove proteins. Up to now there are no valid data how much and under which circumstanzes foam fractionaters export nitrogen from coral reef aquaria. Around 1990 the skimmate of a foam fractionater running at a low nutrient coral reef tank was twice given to a lab to test for total nitrogen (Kjeldahl method) : in both cases there was no nitrogen in the skimmate. That means that the skimmate probably consisted of slowly degradable fats and carbohydrates instead of proteins which were easily digested by bacteria before the water entered the skimmer.

Reliable methods to remove nitrogen from aquarium systems are denitrification, either with an organic food source or with sulfur, or harvesting of organisms like algae in algal turf scrubbers. But at nitrate levels near zero algal turf scrubbers may introduce nitrogen to the system when N_2-fixing cyanobacteria are growing (Adey and Loveland, 1998). A newer method is to add a carbohydrate like ethanol (Kokott and Mrutzek, 2004) to the aquarium which is immediately used up by bacteria which incorporate nitrogen and phosphorous from the nitrates and phosphates in the water into their growing biomass. The bacteria either go into the foodchain of the aquarium or are skimmed (harvested). The results ref. to NO_3^- and PO_4^{3-} are positive as long as the amount of carbohydrates is under control. But it remains open if the increased oxygen demand and increased number of bacteria in the water are a disadvantage or not. Increased bacterial numbers in the water give a slight increase in turbidity which might be undesirable especially in larger displays.

But all methods based on harvesting do not only selectively remove nitrates, but also trace elements which are part of the harvested biomass. The supplement of trace elementes has to compensate this loss.

Mechanical filtration of particulate organic N may help to remove N from the system if the filters are cleaned very often, at least daily. Otherwise particulate organics are quickly degraded (Klee, 1979) and release dissolved compounds to the water.

Removing detritus (excessive food, faeces) only helps removing nitrogen when it is done on a frequent basis.

Foam fractionating and mechanical filtration remove living food organisms and plankton, which might be an important food source for the kept corals, from the water.

Under certain circumstances N might be brought into the aquarium system by N_2-fixing cyanobacteria. This point is covered in detail later.

After the startup of an aquarium ammonia and nitrites are no longer relevant and often nitrates are the only nitrogen fraction which is measured on a regular basis. But measuring nitrates in seawater is comparatively inaccurate. Double measurements increase the reliability. The results should be taken more as a tendency, not as accurate numbers (LaPointe, 2004).

Phosphorous

The phosphorous cycle inside the aquarium is shown in Figure 2.

Different to the nitrogen cycle feeding fish and invertebrates is not the only source of phosphates in coral reef aquaria. Lime stone reactors filled with coral gravel or fossil limestones are an often underestimated source of phosphates. Coral gravel has an average content of P of 250 mg. kg^{-1} with peak values up to 500 $mg.kg^{-1}$ (Entsch, 1983; Chevalier,1987). But wherever calciumcarbonate precipitates inside the aquarium, some phosphates are incorporated into these precipitates. Calcareous sediments from different aquaria had contents of P from 202 to 470 $mg.kg^{-1}$ (Luther and Pawlowsky, 1997; 1998a; 1998b; 1999a; 1999b). Adding lime to a coral reef aquarium is crucial not only for hard corals and it makes a great difference, whether the lime is added as P-containing coral gravel dissolved in a lime stone reactor, or if P-free Kalkwasser (Wilkens 1973) or P-free solutions of $CaCl_2$ and $NaHCO_3$ / Na_2CO_3 (Pawlowsky, 1994; Balling, 1994) are used. The early successes in coral husbandry were reached using Kalkwasser as the Ca-source. Although nobody cared about phosphates in those days, the Kalkwasser helped to keep the phosphates low in the early coral reef aquaria. The supplementation of lime is closely coupled to the cycle of phosphorous in coral reef tanks and should be kept in mind if elevated levels of P have to be managed. The binding of P in calcareous precipitates seems to be better if the level of magnesia is in the natural range of 1,300 $mg.L^{-1}$ instead of lowered levels (Pawlowsky, 1999).

Removing fine calcareous sediments from a system prevents precipitated Ca-P-compounds from dissolution which may take place in the bottom layer when a higher organic load leads to higher CO_2 production and decreased pH-values. Removing fine calcareous sediments can be done by mechanical filtration or by periodic removing sediments and detritus.

Harvesting organisms from the system as with algal turf scrubbers is a possibility. But as mentioned before, this method also removes all other trace elements from the system which are incorporated into the harvested organisms.

Up to now the foam fractionater did not prove to be a major exporter of phosphorous from low nutrient coral reef aquaria.

If elevated levels of P occur they are best treated with a slow running (bypass) filter (Pawlowsky, 1995; 2006) filled with phosphate removing material (see Chapter 27) such as the iron based granular ironoxidhydroxid, which is widespread in the meantime and available under different brands. The slow running bypass filter, if properly designed, results in zero phosphates at the filter outlet which gives the opportunity to control its function. It is easy to detect when the material is exhausted and it may be changed long before the phosphate level raises in the aquarium itself.

A special experience in the P cycle is the PO_4^{3-}-pool. This pool was discovered when the elevated P level in a coral reef tank should be lowered by subsequent water exchanges of about 50 % each. The result was that always immediately after each water exchange the

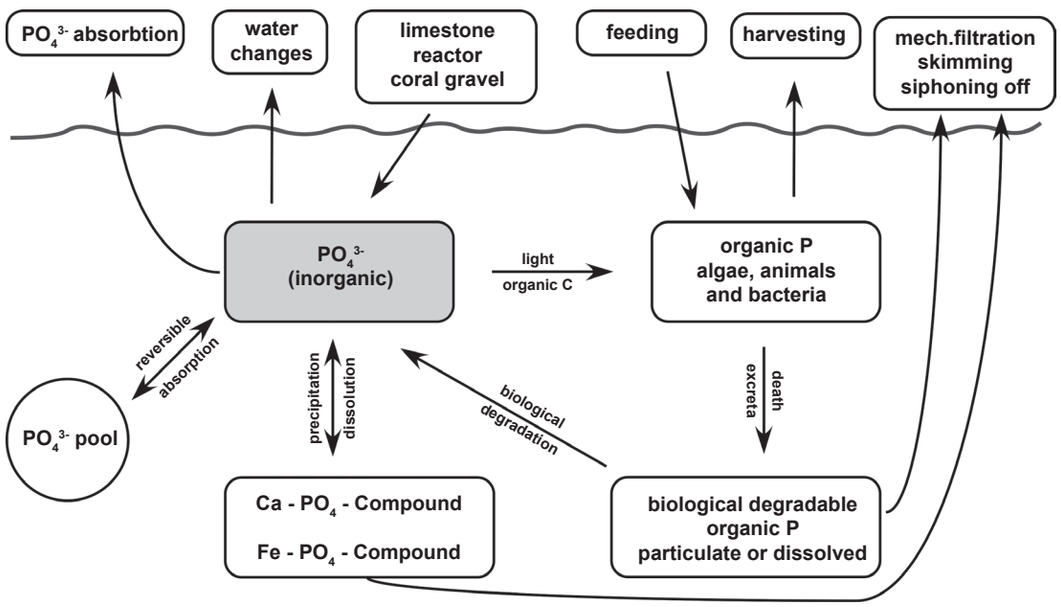

Figure 2: Phosphorous cycle in aquaria.

measurable ortho-PO_4^{3-}-level drops down to 50 % of the initial value but during 2 - 3 days recovered to about 90 % of the initial value before the water exchange. These results suggested the hypothesis of a PO_4^{3-}-reservoir which is not in the open water because it would be removed by the water exchange too. I suggest that the measurable ortho-phosphates in the water are in an equilibrium with phosphates which are weak bound to surfaces somewhere in the tank. Calculating the pool with the data of the recovered PO_4^{3-}-level after 50 % water exchanges suggests that this pool (including the measurable ortho PO_4^{3-}) might be about three times as big as the measured dissolved ortho phosphates alone (Luther and Pawlowsky, 1997; 1998a; 1998b; 1999a; 1999b).

This hypothesis was further supported by results in connection with the use of slow running PO_4^{3-}-filters. Although the outlet of the filters had zero PO_4^{3-}, the decline of the PO_4^{3-} in the tanks was much slower as would be expected by calculating the total amount of ortho phosphates on the basis of the measured values and the removal rate of the filter.

The result of this PO_4^{3-}-pool is that in a new tank with a slight overload of phosphates the measurable ortho PO_4^{3-} does not raise as quickly as might be expected but delayed. But if higher PO_4^{3-} levels have to be treated more efforts are necessary to lower the ortho PO_4^{3-} level.

Measuring ortho PO_4^{3-} is reliable without problems. The only thing to be considered is: do not try to measure very low values of ortho PO_4^{3-} with a test that promises to measure high values as well. Then it will probably be inaccurate at very low values. A factor of 10 from the lowest detectable level to the maximum is okay.

Aquarian levels of N and P

What levels of N and P should be maintained in a coral reef tank?

Is it necessary to imitate natural conditions?

Yes and no !!!

Like many other organisms from nutrient poor ecological niches corals have an advantage over their competitors in their niche. But if the competitors are removed corals grow at even higher nutrient levels.

But from the experience of many aquaria, my own as well as many others, best results refering to the appearance and growth rates of the corals are reached at low nutrient levels. Especially low phosphate levels are recommended.

0.03 to 0.05 $mg.L^{-1}$ of measurable ortho phosphate seems to be best. In this area the corals have a good growth and show good and natural coloration. With higher PO_4^{3-} levels often the coloration of colored corals tends towards brown. Additionally, the growth of the calcareous skeleton of hard corals may be lowered because PO_4^{3-} and organic P-compounds may act as crystal poisons (Simkiss, 1964).

Below 0.03 $mg.L^{-1}$ ortho PO_4^{3-}, which is about 0.32 $\mu mol.L^{-1}$ PO_4^{3-}-P, there is a risk of starvation for some corals (Sorokin, 1995), see table 2.

Table 2: Flows of PO_4^{3-}-P between corals and surrounding water in experiments with radiolabeled $^{33}PO_4^{3-}$; t° of water 22 °C; K_P- initial PO_4^{3-}-P content in water, µmol; A_c- uptake; A_e- release; ± A_t- net changes of PO_4^{3-}-P content in water (after Sorokin, 1989)

Species of coral	K_P	Elements of PO_4^{3-}-P balance (flow rates) $\mu g.kg^{-1}.h^{-1}$		
		A_c	A_e	A_t
Pocillopora damicornis	2.0	170.3	82.5	-87.8
	0.3	75.1	46.5	-28.6
	0.06	3.6	6.4	+2.8
Stylophora pistillata	3.0	53.0	36.6	-16.4
	0.3	28.9	13.9	-14.5
Porites andrewsi	0.16	29.5	44.2	+14.7
Aeropora squamosa	0.16	12.6	11.4	-1.2
Cladiella sp. (symbiotic alcyonacean)	0.16	92.8	97.5	+4.7
Pacifigorgia sp. (ahermatypic gorgonacean)	0.26	78.6	2,019.6	+1,941.0
Leptogorgia sp. (ahermatypic gorgonacean)	0.26	34.7	2,166.6	+2,132.0

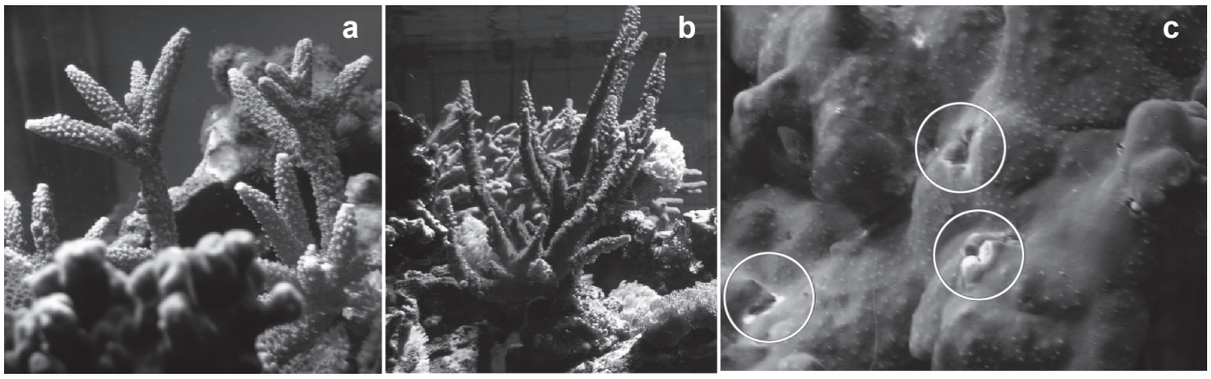

Figure 3: a) Acropora *sp. "green"; b)* Acropora *sp. "blue"; c)* Heliopora *sp. with holes in the tissue*

The green *Acropora* sp. in Figure 3a grows at very low levels of ortho PO_4^{3-} at which the blue *Acropora* sp. in Figure 3b did not grow any more. At the same low PO_4^{3-} level the *Heliopora* in Figure 3c developed holes in the tissue which also occurred at very low levels of nitrates. These holes recovered very quickly when the nutrient level was artificially increased. *Heliopora* may be a good indicator if either nitrates or phosphates become short.

Although Adey and Loveland and Jaubert focused on very low nitrogen levels, aquarium practice showed that it seems to be an advantage if P is the limiting factor not N.

Because nitrates are not easy to measure at very low levels, 2 - 3 $mg.L^{-1}$ of nitrates proved to work very well. It is possible to run a coral reef tank without measurable nitrates. But this is a delicate job and in such a case the risk of cyanobacteria increases very much. As cyanobacteria are able to fix N_2 as their nitrogen source they are able to grow even without nitrates as long as all other nutrients are present (Pawlowsky, 1996).

Cyanobacteria are common in coral reefs (Sorokin, 1995) and in the algal communities of algal turf scrubbers (Adey and Loveland, 1998) but they should be avoided in coral reef tanks besides a few small spots of bluegreens. There are several reasons for that. From the point of a visitor extensive cyanobacteria growth gives a bad appearance of a display tank. But the biological reasons are more important. If larger amounts of cyanobacteria occur in combination with zero nitrates, probably all other eukaryotic algae, including the symbionts in corals, lack nitrates and will starve. But it showed up that in aquaria cyanobacteria also occurred even at measurable nitrate levels and overgrow not only the decoration but even corals. In these cases very often phosphates are also elevated. The well known Redfield-ratio (1934) of 16 : 1 for N : P (molar ratio) is derived from plankton algae. For benthic algae in coral reefs Entsch (1983) found N : P ratios of about 40 : 1. Benthic algae need a better supply with nitrates. If cyanobacteria occur in a greater amount in combination with measurable nitrates phosphates are probably too high and should be reduced. The aim should always be to enhance the growth of eukaryotic algae which are grazed by different animals. But there are nearly no animals in coral reef aquaria that graze on cyanobacteria.

Experience showed that it is very difficult to simultaneously maintain appropriate levels of both, nitrates and phosphates, only by increasing or decreasing feeding of the coral tank. Very often either phosphates are okay and nitrates are too low, or nitrates are okay and phosphates are elevated. The necessary consequence is to either add nitrogen to the system or remove the excessive phosphates. Adding nitrogen to the system can be done with nitrates ($Ca(NO_3)_2$), urea, ammoniumnitrate (NH_4NO_3), aminoacids or mixtures of these ingredients. The supplement should be carefully done on a daily basis, especially with urea, ammoniumnitrate (NH_4NO_3) or aminoacids, because these compounds will undergo further biological processing with an additional demand of oxygen and the risk of a slightly elevated level of ammonia. Only with pure nitrates a reservoir of nitrogen can be obtained for a few days without further risks.

But even if measured nitrates and phosphates are in the best range spots of cyanobacteria may occur, see Figure 4.

A more detailed examination of the microhabitat reveals in most cases that there is a porous structure underlying. That might be bottom gravel, a porous rock or only some sediments and detritus. But in all cases we can assume

denitrification to happen. The following reaction is supposed: the N_2, which is produced by denitrification, is not released to the atmosphere but is immediately fixed again by the cyanobacteria. These have an excellent supply of all nutrients from the underlying substrate: N_2, PO_4^{3-} and CO_2 which all occur at elevated levels in an area of denitrification of nitrates with the help of organics, see Figure 5.

A few spots of cyanobacteria are not a real problem and should be tolerated. To avoid them, it is necessary either to disturb the

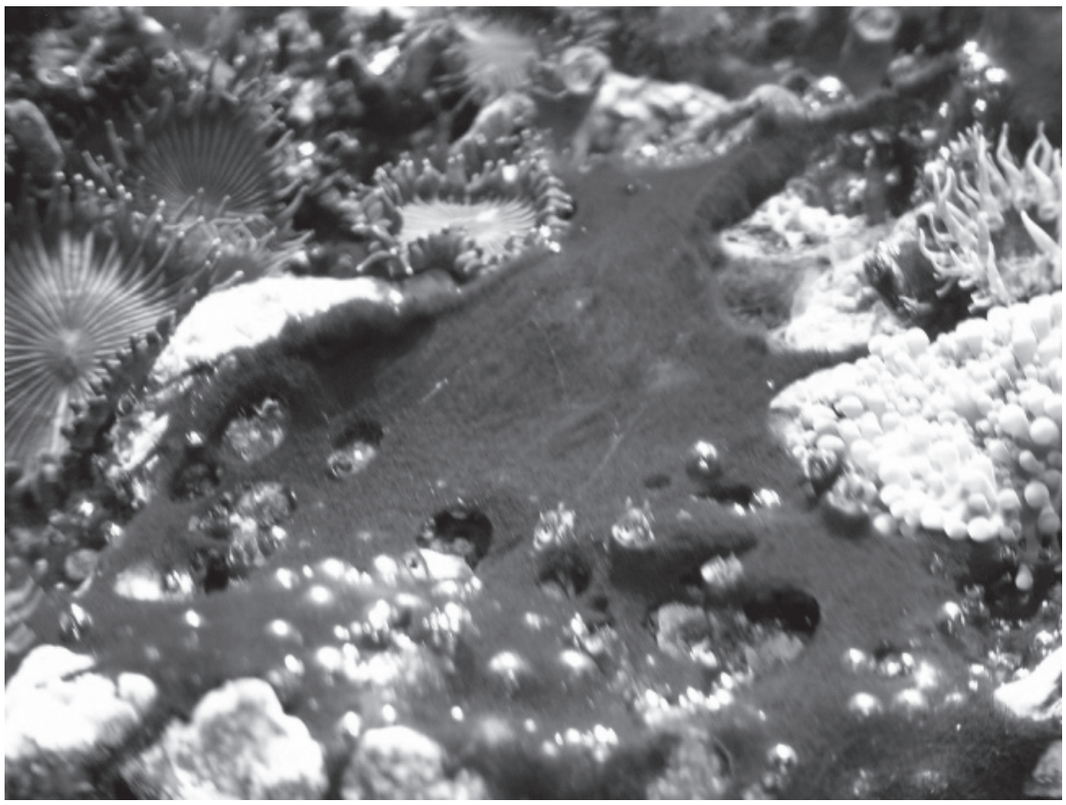

Figure 4: Small spot of cyanobacteria on sediment rich coral gravel.

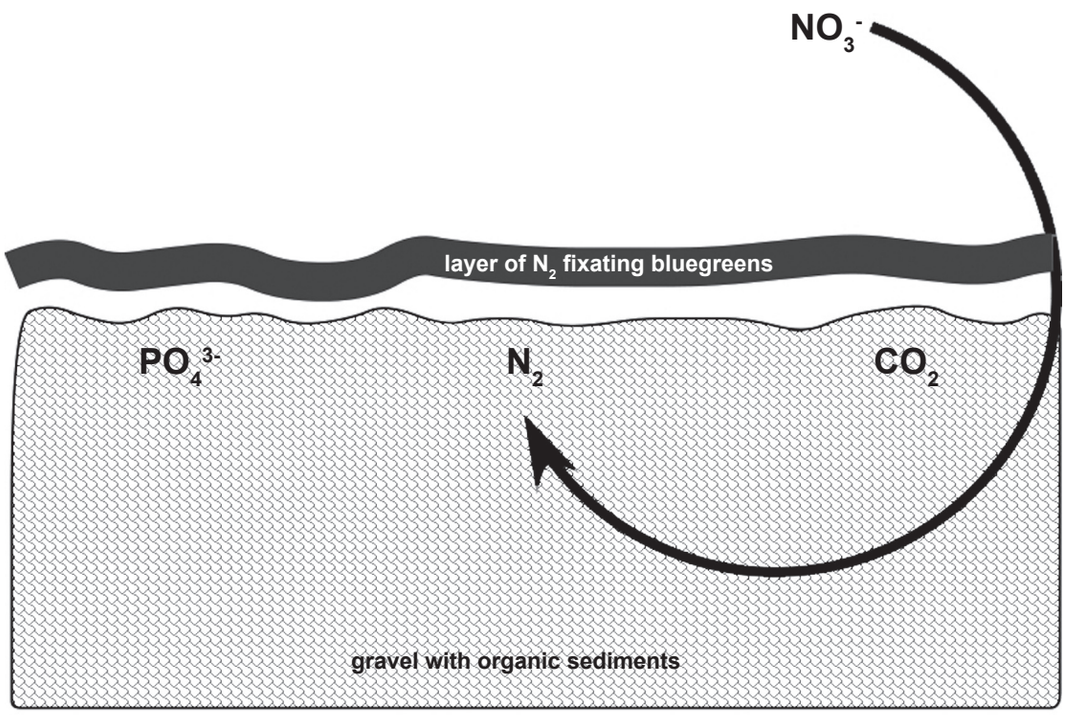

Figure 5: The process of denitrification delivers all macronutrients to N_2 fixating cyanobacteria.

denitrification for example by digging gobies or to increase the current above that area to avoid the formation of such cyanobacteria supporting nutrient situations.
P and N are continually processed along the different pathways outlined in Figures 1 and 2. When nitrates and phosphates are measured, the resulting data are only flashlights and can act as indicators for the processes which are in a steady state equilibrium when the coral tank is running for a longer period so that all processes had time to establish. Changes in feeding, in the technical equipment (light, current or filters) or in the supplementation of trace elements may influence the N or P cycles and lead to new equilibriums.
The knowledge of the N and P cycles help to predict and interpret the results of changes. Therefore all changes should be very well documented and related to the measured data. On the other hand if the values of NO_3^- or PO_4^{3-} suddenly change, it is necessary to search for the cause.
At the recommended levels of NO_3^- (2 - 3 $mg.L^{-1}$) and PO_4^{3-} (0.03 - 0.05 $mg.L^{-1}$) nitrates and phosphates are more or less short term parameters, which can change drastically in a few days. For example with a daily consumption of about 1 $mg.L^{-1}$ NO_3^- and more than 0.01 $mg.L^{-1}$ PO_4^{3-} these reservoirs are depleted in a few days if only feeding is stopped and all other processes continue.

Potassium in coral reef aquaria

Potassium K is very different to nitrogen or phosphorous. As N and P, K is essential for primary production (and therefore an important component of usual NPK fertilizers in agriculture), but the natural level of K in seawater is high, 380 $mg.L^{-1}$ (Sverdrup, 1942; Spotte, 1979), similar to Calcium Ca.
Whenever primary production occurs, in nature as well as in aquaria, K is incorporated into the tissue. In closed systems with high primary production like coral reef tanks there is a permanent loss of K. Depending on the amount of water changes K will level out at an equilibrium significantly lower than the natural level. This can be confirmed by simple computed simulations with the help of a personal computer.

The question is: does this cause deficiency in the K supply of the primary producers?
It was the missing growth of red coralline algae that led to the supplementation of magnesium (Mg) to coral reef tanks (Pawlowsky, 1999). When the level of Mg dropped down to about 900 $mg.L^{-1}$ instead of natural 1,300 $mg.L^{-1}$, growth of red coralline algae stopped. And Mg, similar to K, is not only a macroelement in seawater and a component in the skeletons of red coralline algae but also plays an important role in many biological processes.

Unfortunately up to now, no simple method exists to measure K in seawater to produce reliable data. But there are several experiences indicating that at least in some aquaria the primary production is reduced due to a lack of K.
It was in 1992 when potassiumnitrate (KNO_3) was added to coral reef tanks as a supplement for nitrates. The observed results could not be explained by the increase of nitrates alone. At the same time in the aquarium of another aquarist Aiptasia were reduced by using a concentrated solution of potassiumhydoxid (KOH). After every treatment this tank flourished for some days. After these observations specific trials were made which confirmed the positiv effect of adding potassium to the aquaria. Since then K was added to marine aquaria with changing doses.
The following effects could be observed:
- better growth of all photosynthetic organisms,
- more polyps at SPS,
- intensified branching of SPS,
- less „asthenic“ growth of branching SPS,
- intensified colors of colored corals,
- often a higher demand of macronutrients, due to the increased primary production.

The supplementation of K amplified not only coral growth, algae also did benefit from this additional K. But algae can be removed by appropriate grazers.
Since 1995 several trials with K were conducted in different aquaria of other aquarists. In most cases an initial dose of 50 $mg.L^{-1}$ was given and one or more of the above mentioned effects could be observed within one week.
After getting the 2nd edition of Adey and Loveland (1998) around 2000 a very hidden hint to supplement K could be found, which was not in the 1st edition. This is very understandable because the export of plant biomass for the removal of nitrogen is a major issue of the propagated algal turf scrubbers. And with plant biomass not only N is exported but also K and all other trace elements incorporated.
Afterwards data about potassium levels in aquaria should be gained and a Dr. Lange

potassium testkit was bought. An old but functioning photometer was provided by the salesman and some measurements were done. The seawater had to be diluted 1 : 10 to meet the range of the test of 8 - 50 mg.L^{-1} K. The possible deviation of the measured results is ± 5 mg.L^{-1}. Multiplied with the dilutionfactor of 10 that gives a deviation of ± 50 mg.L^{-1} in seawater. The results were not satisfying and no further information could be gained from them.

A very similar picture occurred when in 2006 two potassium testkits became available in the german aquarium trade. Besides the necessary dilution of 1 : 10 it was very difficult to decide what would be the right testvalue. The discussions in the hobbyist internet forums showed that the results that most aquarists got with these tests were probably too low. But many aquarists added potassium to their aquaria and a high percentage observed changes in their tanks. They expected positive effects on their corals. And some got these positive effects but others described algal problems and stopped the supplementation of K. But even the observed algae problems indicate a lack of potassium. Potassium can not be blamed for algae problems if other nutrients like phosphorous might be too high.

Up to now the knowledge about potassium and its behavior in closed marine systems is very low. The available testkits are not appropriate to get reliable data. For heavily planted freshwater aquaria supplementation of potassium is a standard (Sears and Conlin, 1996) but freshwater contains only small amounts of K which are used up very soon. So supplementation is a must. The observed effects in coral reef aquaria suggest that at least some suffer from potassium deficiency. Possibly potassium is part of the missing link to overcome the „old tank syndrome“ (Sprung, 2006).

So potassium should be cared about and with time we will learn more about the role it plays in coral reef aquaria.

A simple test to detect potassium deficiency is to add about 50 mg.L^{-1} K to the tank and observe the reaction of the corals and algae. If some of the above mentioned effects occur, potassium might be too low.

The supplementation, which was found by long term observations, now is in the range of 1.0 to 1.5 mg.L^{-1}.d^{-1} (highly lighted aquaria get the upper value).

Some of the public aquaria own labs with a very good equipment and should be able to provide reliable data about potassium.

CONCLUSION

Continuity in water chemistry is crucial for long term success in coral husbandry. Big spawning colonies (see Chapter 35) only develop when they experience no major setbacks. The management of the macronutrients nitrogen and phosphorous is an important contribution. The dynamics of the nitrogen and phosphorous cycles have to be understood and steady state equilibriums have to be established in coral reef aquaria with low levels of nitrates and phosphates. The role of potassium is not yet clarified, but there is evidence that potassium deficiency may occur in at least some coral reef aquaria, causing a reduced growth of corals (and algae). Further investigations are necessary.

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